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A ROTARY ELECTRIC MACHINE

Technical field

The present invention relates to a rotary electric machine of alternating current type designed to be connected directly to a distribution or transmission network and comprising at least one electric winding. The invention also relates to an electric power plant comprising such an electric machine, and also to a method of exciting a rotary electric machine.

Background art

The rotary electric machine according to the invention may be a synchronous machine, dual-fed machine, external pole machine or synchronous flow machine.

To connect machines of this type to distribution or transmission networks, in the following referred to as power networks, transformers have hitherto been used to step up the voltage to network level, i.e. to the range of 130-400 kV.

Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-527. These generators comprise windings of high-voltage cable in which the insulation is divided into different layers with different dielectric constants. The insulating material used consists of various combinations of the three components mica-foil mica, varnish and paper.

It has now been found that, by manufacturing the above-mentioned winding of the electric machine from an insulated electric high-voltage conductor with a solid insulation of a type similar to that used in cables for power transmission, the machine voltage can be increased to such levels that the machine can be connected directly to any power network without the use of intermediate transformers. A typical operating range for these machines is 30 to 800 kV.

Nowadays static exciters or brushless exciters with rotating diode rectifier bridges are used in rotary electric machines. The excitation equipment is frequently required to be able to produce a peak voltage and peak current of 1.5 to 3 times greater than equivalent magnitudes in the case of rated load excitation for the machine in question, for a duration of 10-30 seconds. The excitation equipment shall also be able to produce a field current equivalent to the rated load excitation current for 25% voltage on the stator terminal of the machine. The excitation system shall preferably be "maintenance free", i.e. an excitation system without

slip rings. The response and transient times at network disturbances shall also be rapid, i.e. the excitation equipment shall be able to generate both positive and negative field voltage. In the case of synchronous compensators, the excitation system shall generally be able to produce both positive and negative field current and demands for peak voltage factors greater than 3 times the rated load excitation voltage may occur.

Brushless exciters eliminate the problems of dirt from carbon dust from brushes and slip rings. However, brushless exciters in accordance with known technology exhibit poorer control performance than static exciters.

The object of the present invention is thus to provide a rotary electric machine that can be connected directly to a power network and that is provided with a "maintenance free" excitation system with improved control performance, and an electric power plant comprising such an electric machine, as well as to propose a method for excitation of a rotary electric machine.

Description of the invention

This object is achieved with a rotary electric machine of the type described in the introduction, having the characterizing features of claim 1, an electric power plant in accordance with claim 17 and a method in accordance with claim 18.

The insulating conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strands, an inner semi-conducting layer surrounding the conductor, a solid insulating layer surrounding this semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cables which are bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in

diameter. In the present application the term “flexible” is used to indicate that the winding is flexible down to a radius of curvature of the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in the radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butylymp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable that their coefficients of thermal expansion are of the same order of magnitude. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding with these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

By providing the electric machine in question with a brushless excitation system switchable between positive and negative excitation, a "maintenance free" system is obtained having rapid response and transient times at network disturbances, for instance, since the excitation system is able to generate both positive and negative field voltage and thus positive and negative field current.

According to an advantageous embodiment of the machine in accordance with the invention, the excitation system comprises two controllable antiparallel-connected current converter devices for feeding the field winding of the alternating current machine, a two-way field over-voltage protection means or discharge circuit con-

nected across the field winding, and also control equipment for controlling the current converters and over-voltage protection means or discharge circuit. This is a simple construction requiring no galvanically separated supply sources and current-limiting reactances and no separate short-circuiting devices for extinguishing conducting thyristors. The excitation system is also well suited for synchronous machines such as synchronous compensators. The present invention thus exploits the ability offered by semiconductor technology to temporarily change the polarity in a simple manner, which facilitates rapid commutation of the field current from static current converter bridge to short-circuiting circuit and vice versa when a change of current direction is required in the field circuit of the machine.

Brief description of the drawings

To explain the invention more clearly embodiments of the machine in accordance with the invention, selected by way of example, will now be described in more detail with reference to the accompanying drawings, in which

Figure 1	shows the insulated cable used in the machine in accordance with the invention,
Figure 2	shows a circuit diagram of the excitation system in the machine in accordance with the invention, and
Figures 3a-f	show the voltage and current variation upon bridge switching in the excitation system shown in Figure 2.

Description of a preferred embodiment

Figure 1 shows a cross section through an insulated conductor 11 intended for use in the windings of the machine in accordance with the present invention.

The insulated conductor 11 thus comprises a number of strands 35 having circular cross section and consisting of copper (Cu), for instance. These strands 35 are arranged in the middle of the insulated conductor 11. A first semiconducting layer 13 is arranged around the strands 35. An insulating layer 37, e.g. XLPE insulation, is arranged around the first semiconducting layer 13. A second semiconducting layer 15 is arranged around the insulating layer 37. The insulated conductor is flexible and retains this property throughout its service life. Said three layers are constructed so that they adhere to each other even when the insulated conductor is bent. The insulated conductor has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm^2.

Figure 2 shows a circuit diagram for the excitation system in the machine in accordance with the invention. The field winding 4 of the machine, which may be stationary or rotating, is connected to two antiparallel-connected current converter bridges 1, 2. A two-way over-voltage protection means comprising two antiparallel-connected thyristors 8, 10 with associated ignition circuits 12, 14, is also provided over the field winding 4.

The current converter bridges 1, 2 are supplied from a source 16 and controlled from a switching logic 18 via control pulse amplifiers 20, 22. A control pulse generator 28 for the current converter bridges 1, 2 in the form of thyristor bridges is also arranged to emit control pulses to the pulse amplifiers 20, 22. Measuring instruments 24, 26 are also arranged to measure the currents IFB1 and IFB2, respectively, from the current converter bridges 1, 2, and transmit the measured results to the switching logic 18 for control purposes. Connection of the thyristors 8, 10 of the over-voltage protection means is also controlled from the switching logic 18 via the ignition circuits 12, 14. The over-voltage protection means is connected to a current-limiting resistor R. In the system with field breakers this resistor R serves as discharge resistor.

The procedure for switching from bridge 1 to bridge 2 is as follows: Initially bridge 1 is assumed to be conducting, which means that the current direction IF through the field winding 4 is positive, see Figures 3a and 3b. The control signal U_{st}, see Figure 2, to the control pulse generator 28 and the switching logic 18 will be negative, resulting in bias reduction and thus a change of polarity of the bridge 1, see Figure 3a. The time interval for bias change, t_2-t_1 according to Figure 3b, from maximum positive peak voltage to maximum negative peak voltage is approximately 8.3 ms at a frequency of 50 Hz and 6-pulse two-way bridge.

At the time t_3, when the current I_{FB1} is still greater than 0, an ignition pulse is transmitted to the discharge thyristor 10 and a blocking signal to the bridge 1. As a result of the free-wheel effect at negative bias, a momentary transmission of excitation current I_{FB1} to the over-voltage protection circuit is obtained, and the bridge 1 becomes currentless. A signal from the measuring instrument 24 that the bridge 1 is currentless initiates unblocking of bridge 2 and blocking of the ignition circuit 14 for the thyristor 10. The time interval t_4-t_3 according to Figure 3, i.e. the period from the blocking of bridge 1 until the bridge 2 is connected is approximately 5 ms, see Figure 3. It is apparent from Figure 3d that the current I_F in the field circuit 4 during this switching interval is maintained as a result of the inductance of the field winding 4. As apparent from Figures 3d and 3e, the biased

bridge 2 now forces a current I_R, see Figure 3f, through the thyristor 10 and the current-limiting resistor R, and also a current I_F through the field winding 4 of the synchronous machine. At the time t_5 the field current I_F has changed polarity and the discharge thyristor 10 is extinguished through temporary biasing reduction of the bridge 2, i.e. a temporary change in polarity to force a current in the reverse direction of the short-circuiting circuit or the over-voltage protection means.

A suitable choice of current levels for generating blocking and detecting signals ensures that the time interval is brief for connecting the two-way field over-voltage protection means 8, 10, 12, 14 serving as auxiliary circuit or the two-way thyristor discharge circuit.

Switching from negative current direction to positive current direction at a positive control signal occurs in corresponding manner by temporary connection of the thyristor 8 in the over-voltage protection means.

An embodiment of the rotary electric machine in accordance with the invention is described above by way of example. However, several modifications are of course feasible within the scope of the invention. The principle described can thus be used for both stationary and rotating thyristor bridges for exciting synchronous machines or for supplying motors for drive systems. Temporary or pulsed biasing reduction may also be used to reset an activated over-voltage protection means. In a first phase, an over-voltage signal then gives a signal for alarm and resetting the protection means. A continuous error signal after a number of resetting attempts will generate a tripping signal.

The introduction and use of extinguishable semiconductor elements can also shorten the time interval for switching between positive and negative excitation or vice versa. The introduction of extinguishable semiconductor elements in the two-way over-voltage protection makes temporary reversal of the field voltage unnecessary in order to extinguish an activated and conducting semiconductor element.